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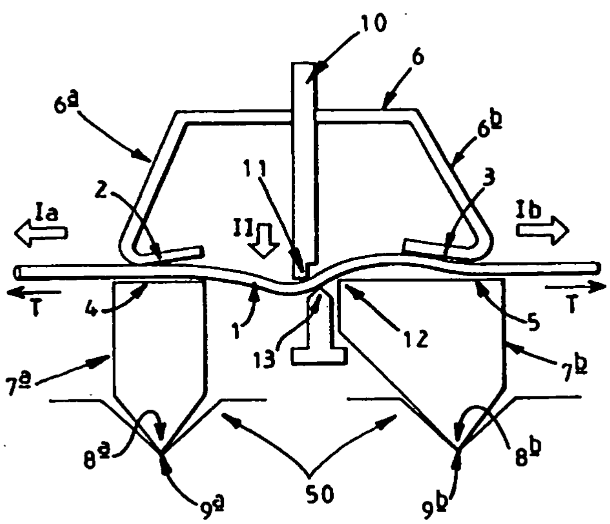

(57) Abstract

An improved device or tool is provided for cleaving angled ends onto at least one optical fiber (1) in which spring means (6) and co-operating pivotally mounted clamping blocks (7a, 7b) are employed to clamp and tension the optical fiber (1) with tension (T). A sharp corner edge (11) of an anvil (10) is used to locally deflect or displace the fiber (1) and bend it about the opposing sharp corner edge (12) of the clamping surface (5) of one of the clamping blocks (viz 7b) so that the fiber experiences a localised shear force. The resultant stress is a superposition of tension and shear and is directed away from the axis of the fiber (1). An acutely angled blade (13) is operable to score the fiber (1) at a point between the two opposing corners (11, 12). The fiber (1) cleaves with ends which are consistently angled at between 1° and 20° (preferably 5° to 10°) away from the perpendicular to the fiber axis.

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TOOL FOR ANGLED CLEAVING OF OPTICAL FIBERS OR THE LIKE

The relative widespread and ever increasing use of optical fiber materials as means for carrying optical signals for telecommunications has created a need for devices or tools to cleave the glass of the optical fiber. The cleaved end of the optical fiber should be largely smooth and free from surface imperfections.

When the glass fiber is terminated, light beams travelling into or out of the optical fiber will have a portion of their light reflected from the endface of the fiber. If this reflected light is directed back towards the source of the light beam it will have deleterious effects, including an increase in the optical noise level and possibly disturb the operation of the light source such as a semiconductor laser.

However, if the cleaved end of the fiber is not perpendicular, the reflected light will be directed in a direction away from the incident light beam path and will not affect the light source. Similarly, if light travelling in an optical fiber exits an angled cleaved end of the fiber, for instance in a mechanical splice, then any light reflected from the cleaved end will be directed away from the optical axis of the glass fiber, hence the reflected light will not be guided by, and will not propagate back down, the optical fiber. Consequently, no back-reflection will be observed due to the cleaved end. A cleaved end angled at approximately 6°-8° away from the perpendicular will reduce the back reflection of light in an optical fiber to less than -60dB.

Applications for angled cleaved ends designed to eliminate back-reflections are found in the pigtailing of optical devices such as semiconductor lasers and in the manufacture of optical couplers, fiber Bragg gratings, mechanical splices etc. Suppression of end reflections could also find applications in the design of solid-state laser cavities such as Nd:YAG and in the manufacture of Selfoc lenses.

Applicants prior abandoned International Patent Application No PCT/GB96/00919 (published under No WO96/33430) discloses details for the design of a tool for cleaving perpendicular ends onto glass fiber. Other, different, cleaving tools also exist. However, only a few cleaving tools exist which deliberately and controllably cleave angled ends onto optical fiber, including those from York Technology UK and Mars-Actel France. However, these tools require several steps for their operation and hence are difficult to use for an unskilled operator. Both tools tension and twist the fiber before cleaving the fiber with an angled end in the range of 5°-10°. The torsion present in the fiber gives angled cleaved ends but with the presence of surface roughness or hackle which becomes more severe with increased fiber end angle. Furthermore, these tools are only capable of angled cleaving a single optical fiber whereas optical fibers are often arranged in the form of a ribbon containing upto 16 fibers.

It is a principal object and purpose of this invention to provide an improved tool for cleaving angled ends onto single or multiple optical fibers which can reliably effectuate optically flat end faces in the region of the fiber core or cores with end angles β in the range of 1°-20° and preferably in the range 5°-10° away from the perpendicular to the fiber axis, in order to reduce the back reflection from the cleaved glass surface or surfaces. The cleaved surfaces should be mirror-smooth and largely free from defects in the region of the core of the optical fiber.

It is also desirable to provide an arrangement for cleaving optical fibers at specified and precise distances from the end of the fiber coating or from a constraining device such as a ferrule or connector.

Basically according to this invention a tool for angled cleaving of at least one optical fiber or the like in which a pair of spaced apart clamping or locating means is provided for holding or retaining a length of a said optical fiber or of each such fiber there between, together with means for effecting localised deflection or bending of the length of optical fiber and also blade means for scoring the length of optical fiber in a required sequence of operation of the tool in order to initiate and cause angled cleaving of the length of optical fiber; the tool being characterised by the means for effecting localised deflection or bending of the length of optical fiber comprising a shear force member closely offset from a further shear force member for their substantially opposite transverse line or edge contact or engagement with the optical fiber, said first mentioned shear force member being

operable for shear or like movement of its edge formation relative to a co-operating substantially fixed transverse edge formation of further shear force member which is substantially fixed in the tool whereby localised deflection or bending of the length of optical fiber is effected between the edge formations of the shear force members in obtaining angled cleaving of the fiber as a result of its scoring by the blade means.

Various embodiments and examples of the invention will now be described with reference to the accompanying enlarged scale diagrammatic drawings in which:-

Fig. 1 shows an optical fiber clamped between two upper clamping surfaces and two lower surfaces, with the presence of an anvil deflecting the fiber and an edge scoring the tensioned fiber;

Fig. 2a shows an enlarged view of the tensioned optical fiber, sheared between the corners of the anvil and a lower clamping surface and being scored by the edge of a sharp blade;

Fig. 2b shows the fiber after cleaving;
Fig 2c shows skin tension and compression of a bent fiber;
Fig. 3 schematically shows an angled blade scoring an optical fiber where the blade's motion is at an acute angle α a to its edge due to rotation around a pivot;
Fig. 4a shows a side view of a cleaved fiber end showing the cleaved end angle β approximately constant across three-quarters of the fiber including the core (the angle β is exaggerated for clarity in the drawing);
Fig 4b shows an end face view of the cleaved end shown in Fig 4a;
Fig. 5 shows a ribbon of fibers being angle cleaved after having been clamped, sheared and scored;
Fig. 6 shows a tensioned and cleaved fiber being angled cleaved where the fiber is firmly held upto the point of shearing;
Fig. 7 shows the angled cleaving of a fiber held in a connector.
Figs 8, 9 and 10 are general views similar to Fig 1 but each showing a further development of the tool;
Figs 11a and 11b are general views showing still further developments of the tool, and
Figs 11c and 11d are respectively a side view and an end view of a fiber as cleaved by the tool shown in Figs 11a and 11b

Like parts are referred to by the same, or similar reference numerals throughout Figs 1 to 10 of the drawings whilst any dimensions or other values quoted herein are given by way of example only and may be varied accordingly to practical requirements.

This invention reveals the details of the design of a tool for controllably cleaving single or multiple optical fibers with cleaved end angles β in the range 1°-20° and preferably in the range 5°-10° away from the perpendicular to the axis of the fiber.

In particular the aforesaid prior International Patent Application describes details of a tool for perpendicular cleaving of optical fiber, comprising a pair of spaced apart clamps operable for holding the fiber in a tensioned condition for scoring by a blade whereby subsequent cleaving of the fiber is effected by the tension thereon, whereby spaced apart clamps for holding the fiber are operable on clamping pressure both to clamp and tension the fiber, incorporating also a two-armed anvil which displaces the fiber in addition to the applied tension. At a point in between the arms of the anvil, the tensioned and bent fiber is scored by a blade edge which is moved at an acute angle to the fiber, so causing the fiber to cleave. The tension present in the fiber is aligned along its axis, and because the cleave propagates perpendicular to the internal stress, the resultant cleaved end face is perpendicular to the axis of the optical fiber.

The prior International Patent Application also reveals details of the angled cleaving of a fiber or fibers using a secondary anvil. The clamped and tensioned fiber was displaced by a one-armed primary anvil and was also displaced in the opposite direction by a secondary anvil. Because the tensioned fiber was displaced in opposite directions, it experienced a shearing action at points between the two anvils. The resultant stress in the fiber was a superposition of tension and shear. Consequently, when the fiber was scored at a point between the two opposed anvils, the cleave propagated perpendicular to the resultant applied stress, i.e. at an angle away from the perpendicular to the axis of the fiber, creating an angled cleaved end. This technique was achievable for both single and multiple fibers.

In this invention, improvements to this technique of angled cleaving are revealed, whereby the secondary anvil is incorporated into one of the clamping surfaces, so simplifying the mechanism, yet still achieving the goal of angled cleaving single and multiple optical fibers.

Fig. 1 shows an arrangement of a pair of the clamps 6a, 7a; 6b, 7b which both clamp and tension at lease one optical fiber. The optical fiber 1 is stripped and placed between the two polished upper clamping surfaces 2, 3 and the two polished lower clamping surfaces 4, 5. The upper two clamping surfaces 2, 3 are part of a common spring member 6. Downward pressure on the spring member 6 will provide a force with a downward component, so clamping the optical fiber 1 at two positions between surfaces 2 and 4 and 3 and 5. In addition, due to the angle of the clamping legs 6a, 6b of the spring 6, the same downward force has components which are resolved in the directions **Ia, Ib** parallel to the fiber 1, which act to tension it with a force **T**. The bottom clamping surfaces 4, 5 are the surfaces of clamp blocks or jaws 7a, 7b which are pivoted around sharp edges 8a, 8b at their lower ends as they rest in corresponding grooves 9a, 9b in a base part 50 of support structure of the tool and which allows them to pivot in a direction along the axis of the optical fiber. Downward pressure therefore both clamps the fiber 1 at two points and urges the two clamping surfaces 2, 4 away from the other two clamping surfaces 3, 5 in directions **Ia, Ib**, so tensioning the fiber.

In a known manner support structure or a body of the tool including the base part 50 carries lever or like means (not shown) for imparting downward pressure on the spring 6 and operation of associated movable parts of the tool. This generally applies to further forms of the tool as later described.

Further operation of the tool causes a shear action anvil 10 to descend such that its sharp corner 11 comes into contact with the clamped and tensioned fiber 1. The anvil 10 displaces the fiber 1 in the direction **II** in Fig. 1 until a stop (not shown) is reached such that the fiber is bent by the anvil by a preset amount. In addition, one of the two lower clamping blocks viz the block 7b has a sharp shear action corner 12 which is located close to but laterally displaced from the anvil 10, as shown in Figs 1 and 2a. The displacement of the fiber 1 by the motion of the anvil 10 causes the fiber 1 to be bent at two locations, namely the sharp corner 11 of the anvil 10 and the sharp corner 12 of the lower clamping block 7b. In the region between the corner 11 of the anvil and the corner 12 of the lower block 7b, the fiber 1 is therefore both tensioned due to the spreading apart of the clamps in directions **Ia, Ib** and sheared because it is bent between two opposing sharp corners 11, 12. Consequently, the fiber experiences a resultant stress which is not parallel to the axis of the fiber.

Yet further operation of the tool moves a scoring blade edge 13 to contact the stressed fiber and so score it. The blade 14 with its edge 13 is mounted on an arm 15 which moves about a pivot 16, as

shown in Fig. 3. Movement of the end 15a of the arm 15 in the direction IIIA causes the blade edge 13 to move in the direction of arrow IIIB at an acute angle α, with respect to its edge 13, so scoring the fiber at the acute angle α, and causing the latter to cleave due to the tension therein. Consequently, when the blade edge 13 scores the fiber 1 in the region between the two corners 11, 12 where the internal stress is aligned in a direction away from the axis of the fiber, the fiber cleaves perpendicular to the internal stress in the fiber, and so the resultant cleaved end is angled away from the perpendicular to the fiber axis. The acute angling of the blade edge 13 minimises the forces of the edge 13 scoring the fiber 1 and hence introduces the minimum extra stress into the fiber as its cleaves, ensuring that the resultant stress at the time of cleaving is well controlled.

As shown in Fig 2c the blade edge 13 scores the displaced fiber at a location where the fiber skin is under tension. Skin tension T and compression C is also indicated in Figure 2c.
The cleaved end should be smooth and defect-free. The tension **T** applied by the action of the clamps is necessary to propagate the cleave. However, too much tension will cause the cleave to propagate too fast, creating hackle on the cleaved end. If too little tension is used, the scoring edge 13 will be required to penetrate too deeply into the fiber to initiate the cleave, giving a poor cleave. An applied tension of approximately 200 grams gives good cleaves.

Preferably, the fiber or fibers should be scored at a point or points close to the position of the corner 11 anvil 10 so that the blade bites into the outside of the curve of the displaced fiber such that $x_1 < x_2$ in Fig. 2a. Scoring at a point further away from the action of the anvil, i.e. closer to the corner 12 of the clamping surface, may create substantial blade damage because the anvil is less able to resist the cutting action of the blade and the fiber may be placed under compression at the point of scoring.

Furthermore, the displacement of the fiber by the anvil must be great enough to resist the cutting force of the blade, so requiring only a small score to initiate the cleave, but not so great as to overbend the glass fiber, which would lead to significant lips or roll off of the cleaved end. Fig. 2b shows the anvil 10 displacing the fiber 1 such that there is a vertical displacement between the two end portions 18, 19 after cleaving. A displacement **h** of approximately 150 μ m and a distance x_1+x_2, of approximately 0.8mm will lead to a cleaved end with an angle β of approximately 6°-8° from the perpendicular in the region of the core 17 of a single mode fiber.

The angle of the cleaved end is approximately constant over most of its diameter, including the region of the single mode core 17 as required to reduce the back-reflection as shown in Fig. 4a where the angle β from the perpendicular is exaggerated. However, the region of the glass within approximately one-quarter of a fiber diameter from the point of scoring by the blade has a lower end angle β than the remainder of the cleaved end face. Furthermore, the two cleaved parts of the fiber are not identical. The cleaved end of the end portion 18 to the left of the blade edge 13 in Fig. 2b, and as shown in Fig. 4a, is smooth without any lips; this end portion 18 should be used as the cleaved fiber end for pigtailing optical components, etc. In contrast, the matching angled cleaved end of the portion 19 to the right of the blade in Fig. 2b protrudes from the fiber end and is therefore likely to be damaged and should be discarded as the offcut. Fig 4b is an end face view of the angle cleaved end shown in Fig 4a where contour lines plot equi angle surfaces.

To determine the angle of the cleaved ends, 125 μm diameter optical fiber was stripped, cleaned and placed in the tool and cleaved. The cleaved ends were mounted on a block under an optical microscope using monochromatic light incorporating an interference lens such that interference fringes were observed on the cleaved surfaces. The block was angled at 8.0° and the cleaved fiber was rotated so that its angled end was approximately horizontal such that interference fringes could be seen. When the interference fringes were widely spaced in the region of the fiber core, the cleaved surface was approximately horizontal and the cleaved end angle β in the region of the core of the fiber was equal to the angle at which the mounting block was tilted. When the interference fringes were closely spaced, the end angle β differed from the angle of the block. The angle of the block could be changed to alter the angle at which the fiber was mounted to minimise the number of interference fringes. In this way the end angle β of the core of the fiber can be measured to an accuracy of approximately 0.3°.

30 test cleaves were taken. Their end angle β was measured, with an average end angle of 5.8° and a standard deviation of 0.3°. The cleaved ends were mirror smooth with no significant hackle and the score mark intruded less than 5 μm into the fiber. The tension **T** arising from clamping the fiber was approximately the same as used in the perpendicular cleaving device, as described in the aforesaid International Patent Application, i.e. approximately 200grams. The outsides of the clamping surfaces were approximately 15mm apart. The distance between the corner 11 of the anvil 10 and the corner 12 of the bottom clamping block 7b was approximately 1.0mm; the blade scored the fiber at a distance x_1 of approximately 0.2mm from the corner 11 of the anvil. The anvil

displaced the fiber such that the vertical distance **h** between the two fiber ends after cutting was approximately 150 μm.

The tool was then modified to cleave 200 μm diameter optical fiber. The tension used was adjusted to approximately twice the tension used above, i.e. approximately 400grams. x_1+x_2 was approximately 1.0mm and **h** was approximately 150 μm. 30 cleaves were taken. An average cleave angle of 8.0° from the perpendicular was obtained with a standard deviation of only 0.6°. The cleaved ends were mirror smooth with no significant hackle and a small score mark less than 10 μm deep.

It can be seen from these test results that the tool is effective in consistently cleaving optical fiber with the cleaved end angle β approximately 5°-10° from the perpendicular with a low standard deviation in the end angle achieved.

The tool can also be modified to angle cleave optical fiber of other diameter to those referred to in the above mentioned tests. It is believed that the tool can angle cleave 80 μm diameter fiber and smaller and fiber in excess of 200 μm diameter and also of any other diameters of this order. The tool can also angle cleave fiber of non-circular cross section.

The cleaving tool according to this invention is superior to tools which achieve angled ends by twisting the fiber, such as the York Technology or Mars-Actel cleavers. The variation in the end angle achieved by the present tool is very small because the shear stress is precisely defined by the distances x_1 x_2 over which the fiber is bent. In contrast, prior art tools which twist the fiber to achieve an angled end have an inherently larger variation in end angle because the length over which the fiber is twisted is not well defined because of variation in the position where the fiber is clamped. Furthermore, shearing the fiber between two corners 11, 12 in this invention does not lead to hackle which becomes serious for ends with angles greater than 5° - 8° using a twisting method. Consequently, as a result of this invention angled ends can be cleaved with greater end angles than the prior art tools. End angles β of up to 20° from the perpendicular have been achieved with this tool. In particular, the cleaving tool can cleave 125 μm diameter multi-mode fiber so that the end angle β across the majority of the 50 μm or 62.5 μm core 17 is greater than 10°, so reducing the back-reflection to approximately - 60dB. This is best achieved when x_1 is approximately equal to x_2

The end angle β achieved depends upon the combination of shear and tension forces and can be varied by altering either the deflection **h** of the fiber by the anvil or by changing the distance x_1+x_2 between the corner 11 of the anvil and the corner 12 of the lower clamping block 7b or altering the tension T. To increase the angle β of the cleaved end **h** can be increased, x_1+x_2 can be decreased or the tension **T** in the fiber generated by clamping can be decreased, and vice-versa to decrease the end angle β.

This invention envisages that the angle cleaved onto the end of the fiber can be varied by varying the distance **h** that the fiber is deflected by the anvil. A greater deflection **h** gives a greater end angle β. The amount of deflection and hence the end angle can be controlled by the operator or set in the factory by altering the stop which determines how far the anvil deflects the fiber.

This cleaving tool can also cleave angles onto the ends of all fibers in a ribbon. A fiber ribbon 20 is stripped and placed in the tool, as shown in Fig. 5. Downward pressure on the clamp spring members 6a, 6b clamps the fibers and tensions them. All of the fibers are bent by the same amount by the corner 11 of the anvil, as shown in Fig. 5, and so experience the same shear stress between corners 11 and 12. Consequently, when the fibers are scored by the blade and so cleave, all of them cleave with the same end angle β

This cleaving tool can also be used to cleave optical fibers at specified and precise distances from the end of the coating or other constraining device such as a ferrule or connector 22 (Fig 7). The stripped fiber should be mounted in the tool and located, for instance by means of a clamp or stop, such that the fiber coating or the ferrule is held at a precise distance from the scoring edge 13. Consequently, the angled cleaved end will be located at a predetermined distance from the end of the coating or the ferrule for later use with mechanical clips, such as used in mechanical splicing or in opto-electronic device packages such as laser diodes or detectors. See Figs 8 and 9 as later referred to.

In a development of the invention, the end angle β cleaved onto the end of the optical fiber can be increased for given values of x_1+x_2, **h** and **T** by firmly holding the optical fiber in the region of the sharp corner 12, so that it does not lift up away from the clamping surface 5. This can be achieved by extending the upper clamping surface 3 as shown in Fig. 6. Deflection of the fiber by a given distance **h** by the sharp corner 11 of the anvil will create a greater shear force if the fiber is firmly

held between the co-extensive surfaces 3 and 5 in the region of the point of bending over the sharp corner 12 of the lower clamping block 7b compared to the fiber not being firmly held as it is bent over the corner 12 as in Fig. 1. The greater cleaved end angle β is useful for reducing back-reflection for example in multi-mode optical fiber which requires an end angle in excess of 10° over the entire region of the core.

In a further development of the invention, the device can be used to cleave an angled end onto an optical fiber which is held in an optical connector or other holding device. Fig 7 shows the optical fiber 1 with its coating 21 secured in a connector 22 which is firmly held into the cleaving tool by clamps 23a, 23b. One end of the spring 6 is connected to a firm support 24, while the other end 6b of the spring 6 acts to clamp and tension the optical fiber 1 which is protruding from the connector 22. As previously, the tensioned fiber or each fiber 1 is deflected by the sharp corner 11 of an anvil 10 such that it is bent over the opposing sharp corner 12 of the lower clamping block 7b. The fiber 1 is scored in between the two opposing sharp corners 11, 12 in the region where they are sheared as well as being under tension. The resultant cleaved end will be angled at an angle β from the perpendicular, as is required to reduce the back-reflection. The cleaved ends will be at a predetermined distance **d** from the end of the connector 22 such that the connectorized fiber can be used in optical devices such as semiconductor lasers or mechanical splices. The tool can also be used simultaneously to cleave angled ends onto each fiber in a ribbon fiber connector such as an MT Connector or otherwise.

Still further developments of the invention are now described as follows:

Referring to Fig 8 the tool can be used to angle cleave fiber 1 where the fiber is clamped by its coating 21 and the angled cleave is achieved at a set length from the end of the coating 21. A length of the fiber's coating is stripped and the fiber is placed in the modified tool, as shown in Figure 8. The coating 21 of the fiber is placed in a groove 4a which is provided in the lower clamping surface 4 on the left-hand side of the tool, whereas the stripped portion of the fiber is placed on the polished clamping surface 5 on the right-hand side of the tool. Operating or closing the tool clamps the coating 21 on the left-hand side and the stripped fiber 1 on the right-hand side of the tool. Further pressure urges apart the two clamping points, but because they cannot separate due to the clamped fiber, the force therefore tensions the fiber. The tensioned fiber is then deflected by the corner 11 of anvil 10, shearing the fiber and giving an angled cleave when the fiber is scored. Cleave lengths

as short as 2 mm or less are possible, limited only by the need for the anvil to deflect the fiber. The coating can optionally be pushed against a stop 25 to give a fixed cleave length P from the end of the coating with an accuracy approaching +/-0.1mm.

Clamping the fiber 1 by its coating 21 has an added advantage because the glass is not contacted by the steel clamping surfaces and therefore is not liable to damage, reducing the danger of surface cracks on the cleaved fiber. Preferably the fiber should be enclosed by its coating so that the tension is adequately transferred to the glass so that it can be cleaved, although some slippage of the fiber out of the coating may occur it will still transfer sufficient tension to the fiber. Angle cleaving depends upon a controlled deflection of the tensioned fiber. When the fiber is eccentric in its coating, the distance which the fiber is deflected by the anvil 10 may be changed, leading to a variation in the end angle. Referring back to figs 2a and 2b this variation can be minimised by increasing the distance **h**, whilst maintaining the angle of the cleaved end by increasing x_1 and x_2. The larger value of **h** will minimise the effect of any fiber/coating eccentricity. A value of x_1 of 1 mm will allow a fiber /coating eccentricity as large as approximately 75μm, whilst maintaining a standard deviation in the end angle of +/-1° for an 8° end angle.

Further in this regard and in yet another embodiment of this invention, the tool can be used to angle cleave fiber without stripping off the protective coating 21 of the fiber. The coated fiber is clamped at two positions. The coated fiber is subsequently tensioned and deflected by the anvil 10. The angled diamond blade edge 13 cuts through the coating and then scores the fiber and an angled cleave is propagated by the applied tension and shearing forces. Cleaving the fiber through its coating is particularly effective when the optical fiber 1 is very brittle, as is the case of Tellurite fiber or Fluoride fiber. The coating 21 cushions the clamping of the fiber 1, allowing the fiber to be tensioned without damaging it.

Referring to figure 9, a fiber1 and its coating 21 secured in a connector or ferrule 22 can be angled cleaved without the use of an anvil to deflect the tensioned fiber. The fiber secured in a ferrule 22 is placed in the tool such that the stripped fiber will only pass over the polished bottom clamping surface 5 and the sharp edge 12 if the fiber is deflected. This can conveniently be achieved by angling the lower clamping surface 4 downwards at an angle γ so that the fiber 1 exiting the ferrule is also angled downwards. When the tool is closed, the ferrule 22 and the stripped fiber 1 are clamped, and consequently the fiber is bent into an "S"-shape between the edge 22a where the fiber

1 leaves the ferrule 21 and the corner edge 12. Further operation of the tool tensions the fiber. The fiber is therefore both tensioned and also sheared because the fiber bends due to the angling of the ferrule 22 and this is achieved without the use of an anvil. Consequently when the diamond scores the fiber, the fiber cleaves at an angle. This allows an angled cleave to be performed very close to the end of the ferrule 22. The minimum cleave length is then primarily determined by the closeness of approach of the diamond cutting edge 13 to the end of the ferrule 22. Cleave lengths as small as 0.1mm or less are possible. Cleave lengths up to approximately 2mm are achievable without needing an anvil because the bend on the fiber will resist the cutting force of the cutting edge 13. Significantly longer cleave lengths require the use of an anvil, as described above.

Referring back to Figures 2a, 4a and 4b, the angled cleave is not entirely flat over its whole surface. For a small value of $\mathbf{x}_1$, the core 17 of a single mode fiber is approximately flat, angled at 8°. The half of the fiber end away from the score is approximately flat across its whole semicircle, angled at 8°. However, the angle of the half of the fiber end close to the score approaches the perpendicular close to the point of the diamond score. It has been found that increasing the ratio of $\mathbf{x}_1$ to $\mathbf{x}_2$ increases the area of the centre of the cleaved end face which is approximately flat. When $\mathbf{x}_1$ is approximately equal to $\mathbf{x}_2$, the end face upto a distance of $25\mu m$ from the centre of the core (for a $125\mu m$ diameter fiber) is approximately flat, angled at 8°, before the end angle begins to decrease moving towards the score. This allows the tool to be used for reducing the back-reflection of a multimode optical fiber, for instance $50\mu m$ core/$125\mu m$ diameter optical fiber, because most of the core is at an angle of 8° or greater.

As shown in Figure 10 the tool can also be constructed so that the lower sharp corner 12 is, in effect, separated from the lower clamping jaw 7b. This can be achieved by the use of a separate block 26 which has a sharp corner 27. As before the fiber 1 is clamped between surfaces 2 and 4 and 3 and 5, tensioned and then contacted by the anvil 10 which shears it between the corner 11 of the anvil 10 and the corner 27 of the block 26. The sheared fiber then angle cleaves when it is scored by the diamond blade edge 13. The end angle achieved depends upon the distances **h**, $\mathbf{x}_1$ and $\mathbf{x}_2$. The end angle achieved can be varied by varying the position of the block 26, in the direction IV or V or by its removal so changing the distance $\mathbf{x}_2$. Owing to the confined space (e.g. 1.00 mm) between the anvil corner 11 and the corner 12 of the jaw 7b and also the presence of the blade 13, the block 26 may be more in the nature of a thin blade or shim. This also applies to the blocks 36, 42 as described later.

Figure 4b (as already referred to) shows the shape of an angled cleaved end face, as obtained from interferograms of the cleaved angled end. This shows that the core of the single mode fiber is angled at 8° and is approximately flat. This ensures that the back-reflection is reduced to approximately -60dB. The majority of the semicircle of the fiber end away from the point of the score is also flat and angled at 8°, whereas the end angle of the semi-circle of the end face close to the score point varies between 8° and 0° from the perpendicular. The reduction in angle of the end face close to the point of the score is beneficial in some circumstances. The cleaved end face does not have any sharp corners which might be damaged. Furthermore, the perpendicular portion of the end face is useful for butting against a stop such as might be required mechanically to locate the angle cleaved fiber end in an opto-electronic package. Furthermore, the core of the fiber is dished and so is unlikely to come into contact with any part of such a stop, and therefore the core of the fiber is less likely to be damaged.

The tool is also able to angle cleave polarisation-maintaining (PM) fiber. Three types of 125μm diameter PM fiber were cleaved, as obtained from 3M Inc. of the USA, Fujikura of Tokyo, Japan and from Fibercore of Southampton, England. All three types of PM fiber were successfully angled cleaved with end angles which were similar to that obtained for standard single mode fiber. In general, the angled cleaves were smooth and damage free. However, in particular orientations of the angled cleaves, surface cracks were present on the cleaved end face originating from the stress members which were included in the PM fiber to give its polarisation-maintaining characteristics. These cracks were approximately 30μm away from the single mode core so were unlikely to adversely affect the reduced back-reflection. Prior art tools which use twisting to obtain angled cleaves produces cracks for all orientations of angle cleaved PM fiber.

One practical difficulty of angle cleaving PM fiber is that of orientating the angle of the cleave with respect to the polarisation axis of the fiber. If the PM fiber is glued or otherwise attached to a ferrule or similar and, where the ferrule has an orientation mark such as a flat and the PM fiber is orientated with respect to the flat, then the ferrule can be placed in the cleaving tool in a fixed orientation and the fiber cleaved so that the angle of the cleave is in the correct orientation with respect to the polarisation axis of the PM fiber.

Referring to Figures 11a and 11b the tool is shown in the form of a modified Japanese type of cleaving tool eg as manufactured by Fujikura, Sumitomo Model CT-07, and others. Normally, in such tools the fiber 1 is held at two points between two pairs of clamps 28a, 28b and 29a, 29b which are rubber coated. A sharp slidable blade 30 is passed underneath the clamped fiber such that the blade achieves gentle contact with the fiber, so scoring it. An anvil 31 is then used to deflect the fiber 1 downwards in the region of the score. The fiber experiences both bending forces and tensioning forces due to the downward deflection of the fiber. As the deflection increases, the stresses generated are large enough to initiate a crack originating from the score. The crack propagates across the fiber under the influence of the stresses in the fiber, so cleaving it. Perpendicular cleaves are achieved using these tools in which the anvil has two arms, both of which are coated with rubber at 32a or 32b and the score is located in between the two arms of the anvil. By means of this invention, the tool described above can be modified to angled cleave an optical fiber or fibers as follows:-

For the purpose of the invention the anvil 31 is modified to become in effect single-armed. The fiber or each fiber 1 is held in the two pairs of rubber clamps 28a, 28b and 29a, 29b and is scored by passing the slidable sharp blade 30 underneath. The scored fiber is then deflected downwards by the one-armed anvil 31 such that its arm 33 is offset from the position of the score. The fiber is therefore bent into an S-shape by the shear action referred to below. As the deflection increases, the stresses increase and a crack is initiated from the score. The applied stresses are a combination of shear and tension whose resultant is not along the axis of the fiber. Therefore the resultant cleave is angled away from the perpendicular, as is required to reduce the back-reflection from the cleaved end.

Experimental angled cleaves were carried out as follows:- The normally doubled armed anvil was modified by the addition of a transverse rod 33 to one arm so that there was only one point 34 of contact between the end of the anvil and the optical fiber. A 125μm diameter optical fiber 1 was placed in the tool, gripped by the rubber clamps 28a, 28b and 29a, 29b and scored by the sharp blade 30. The score was at a position at a distance, L_1, of approximately 0.8 mm from the anvil rod contact point 34 and at a distance L_2, of approximately 5.0mm from the rubber clamps 29a, 29b. The fiber was deflected by the one-armed anvil 31 such that it was sheared between the point of contact 34 and corner 35 of the rubber clamp member 29b, the deflection was increased until the fiber cleaved at the location of the score. The resultant cleaved end was angled, with the core at an angle

of approximately 2° from the perpendicular.

In order to increase the end angle achieved, the shearing of the fiber 1 was increased by decreasing the length L_2. This is achieved by the addition of a separate block 36 with a sharp edge 37 between the rubber clamp member 29b and the point of scoring by the blade 30. When the fiber has been clamped and scored, it is deflected so that it is sheared between the line of contact 34 of the anvil rod 33 and the corner 37. The shearing force is therefore greater than without the presence of the block 36 because the distance L_2 is reduced. The fiber therefore cleaves with a greater end angle.

10 consecutive angled cleaves were carried out on a 125μm diameter single mode fiber. The distances L_1 and L_2 were approximately 1.0mm and 2.0mm, respectively. The angle of the core of the optical fiber were measured to be as follows:-

5°, 4°, 4°, 5°, 4°, 10°, 4°, 5°, 9°, 7°

giving an average end angle of 5.7° and a standard deviation of 2.2°.

The cleaved end face was largely free of surface damage, with no roughness from hackle or lips on the surface which protruded into the core of the optical fiber. The shape of the cleaved fiber end is shown in Figure 11c. The end angle increases away from the point of the score. An interferogram of the angled cleaved end is shown in Fig 11d where the contour lines plot equi-angle surfaces. The cleaved end is slightly curved in the region of the single mode core but is sufficiently smooth to give a reduced back-reflection. The fiber end is also slightly dished so that the angle of the core is slightly larger than the angle of the perimeter of the fiber. The part of the surface furthest from the point of score is seen to break away from a smooth curve due to the small tension in the fiber. In the first embodiment of this invention, the applied tension was higher and so the angled end was flatter and did not break away at the back edge. However, the desired reduction in back-reflection depends upon the angle of the core and will not be adversely affected by the roll-off of the fiber end away from the core.

The two ends of the fiber resulting from the cleaving process will be complementary. Therefore, one cleaved end will roll-off whereas the other end will have a protruding shard. The left-hand cleaved

end, as seen in Figure 11c will roll off as seen in Figure 11d, this end should be used whereas the right-hand cleaved end will be very fragile and should be discarded.

From the test result figures it will be noted that some of the end angles achieved were significantly larger than the mean. This was probably because the size of the score imparted by the blade varied. A smaller score requires greater deflection to achieve the necessary stress to propagate the cleave, and the larger deflection leads to an increased shearing force and hence a larger end angle. The variation in end angle can be decreased by careful alignment and cleaning of the scoring blade so that it achieves a consistent depth of score.

Further by means of this invention a standard Japanese cleaving tool can be modified so that it has an adjustable attachment to the anvil. An adjustable rod 38 (Figure 11b) is attached to the two-armed anvil 31 by an arm 39 and pivot 40. When the rod 38 is raised it does not contact the fiber 1 and the fiber is contacted by the two-armed anvil 31, for effecting a perpendicular cleave. When the rod 38 is lowered into its operative position by the arm 39 and pivot 40, the rod contacts the fiber 1 at a point 41, providing a shearing action on the fiber leading to an angled cleave. The rod 38 should not contact the optical fiber before the fiber has been scored by the blade, 30.

In order to achieve an end angle in the range of 5°-8° or greater, a second modification is carried out by the provision of a separate piece or block 42 attached to a lever 43. When the lever is adjusted to apply the block 42, after the fiber has been scored, deflection of the fiber by the anvil rod 38 of the one-armed anvil will shear the fiber over the edge 44 of the block 42 and will lead to an angled cleave. Removal of the block 42 and the anvil rod 38 of the anvil 31 will allow the tool to produce perpendicular cleaves. The block 42 should be far enough away from the point or line of contact of the blade 30 so that the blade is not impeded in its scoring action.

Here again the block 42 can also be adjustable by the lever 43 to change the end angle of the cleave. Movement of the block 42 in a direction IV will decrease L_2 and so increase the cleaved end angle. Movement of the block 42 in the direction V will increase L_2 and so decrease the cleaved end angle.

Thus the end angle achieved is approximately proportional to the ratio of $L_1 + L_2$. When the anvil rod 38 is in position to create a one-armed anvil, with no block 42 present, L_2 is approximately 5.0mm, giving an end angle of 2°. When the block 42 is in position with L_2 decreased to 2.0mm, the

average end angle is approximately 5.7°. It is expected therefore that an end angle of 8° would be achievable when L_2 is approximately 1.0mm An 8° end angle gives a back-reflection of approximately -60dB.

In the manner already referred to the above angled cleaving will cleave all of the fibers in a ribbon in substantially the same way, achieving substantially the same end angle for each fiber. Each fiber in a ribbon is held by the pair of rubber clamps and the slidable sharp blade scores each fiber in the ribbon. In conjunction with the corner 37 or 44 the one-armed anvil 31deflects each fiber by substantially the same amount such that they are all stressed with a combination of shear and tension and hence they all cleave with the same end angle.

In further practical applications of the tool it can also be used to cleave larger diameter brittle objects such as glass Selfoc lenses and glass rods of doped glass used as solid state lasers, cleaving the objects with mirror smooth ends angled away from the perpendicular. The glass rods comprising the Selfoc lenses or the laser rods are clamped at two points and tensioned and sheared by the motion of an anvil, They are scored with an acutely angled blade and cleave at an angle β from the perpendicular. Objects of larger diameter will generally require greater tensions than used above. Scoring may be effected before or after shearing.

Whereas the sequences of operation of the various forms of the tool herein desired above are preferred, it is to be understood that some or all of the operational steps of clamping, tensioning, deflecting (bending) and scoring of the fiber or fibers can be carried out in any described order. Also in some cases the deflecting or bending of the fiber by the anvil 10 or 31 or like means can be such that the fiber is sufficiently tensioned to cause its angled cleavage as a result of scoring by the blade edge 13 or 30. In view of this clamping of the fiber and tensioning thereby is not required and it is only necessary to locate the fiber such as in suitable grooving in the tool support structure or body.

CLAIMS

1 A tool for angled cleaving of at least one optical fiber or the like in which a pair of spaced apart clamping or locating means is provided for holding or retaining a length of a said optical fiber or of each such fiber there between, together with means for effecting localised deflection or bending of the length of optical fiber and also blade means for scoring the length of optical fiber in a required sequence of operation of the tool in order to initiate and cause angled cleaving of the length of optical fiber; the tool being characterised by the means for effecting localised deflection or bending of the length of optical fiber (1) comprising a shear force member (10, 21, 22 or 31) closely offset from a further shear force member (7b, 29b or 26, 36, 42) for their substantially opposite transverse line or edge contact or engagement (11, 21, 22, 34 or 41; and 12, 27, 35, 37 or 44) with the optical fiber (1), said first mentioned shear force member (10, 21, 22 or 31) being operable for shear or like movement of its edge formation (11, 21, 22, 34 or 41) relative to a co-operating substantially fixed transverse edge formation (12, 27, 35, 37 or 44) of the further shear force member (7b, 29b or 26, 36, 42) which is substantially fixed in the tool whereby localised deflection or bending of the length of optical fiber (1) is effected between edge formation (11, 21, 22, 34 or 41 and 12, 27, 35, 37 or 44) of the shear force members (10, 21, 22 or 31 and 7b, 29b or 26, 36, 42) in obtaining angled cleaving of the fiber (1) as a result of its scoring by the blade means (13 or 30).

2 A tool for angled cleaving of at least one optical fiber or the like according to claim 1 wherein said further shear force member (7b, 29b or 26, 36, 42) is provided by a substantially fixed part or jaw (7b, 29b) of the clamping or locating means (6a, 7a; 6b, 7b or 28a, 28b, 29a, 29b) of which corner edge formation (12, 35) of the substantially fixed part or jaw (7b, 29b) or that (27, 37, 44) of a separate further shear force part or piece (26, 36, 42) adjacent thereto provide a said co-operating substantially fixed transverse edge formation (12, 35, 27, 37 or 44).

3 A tool for angled cleaving of at least one optical fiber or the like according to claim 1 or 2 wherein the first mentioned shear force member comprises an anvil (10, 31) operable for shearing movement relative to the further substantially fixed shear force member (7b, 29b

or 26, 36, 42).

4 A tool for angled cleaving of at least one optical fiber or the like according to claim 1 or 2 wherein a fiber member such as a coating (21), ferrule or connector (22) or like attachment serves as the first mentioned shear force member and is movable in effecting a shearing action on the fiber (1) relative to the further shear force member (7b or 26).

5 A tool for angled cleaving of at least one optical fiber or the like according to any of the preceding claims wherein the blade means (13) is operable to score the fiber (1) after the latter has been deflected or bent by the first mentioned shear force member (10, 21 or 22) and at the deflected or bent tensioned portion of the fiber (1) to initiate and cause angled cleaving thereof.

6 A tool for angled cleaving of at least one optical fiber or the like according to any of claims 1 to 4 wherein the blade means (30) is operable to score the fiber 1 prior to deflection or bending of the fiber 1 by the first mentioned shear force member (31 with 33 or 38) whereby the subsequent deflection or bending of the fiber (1) at the point of its scoring effects angled cleaving thereof.

7 A tool for angled cleaving of at least one optical fiber or the like according to any of the preceding claims wherein the clamping or locating means (6a, 7a; 6b, 7b or 28a, 28b; 29a, 29b) is adapted to receive coating (21) or an attachment such as a ferrule or connector (22) of the fiber (1) whereby either a stripped length of fiber (1) or a coated length thereof can be positioned for angled cleaving by the tool.

8 A tool for angled cleaving of at least one optical fiber or the like according to claim 7 wherein stop means (25) is provided for axial end location of the fiber coating (21) when the latter is clamped or located in the tool for angled cleaving of a length of the fiber (1) a preset distance from the located end of the coating (21).

9 A tool for angled cleaving of at least one optical fiber or the like according to any of the preceding claims wherein a jaw (7b) having a corner edge formation (12) as a said further shear force member, has a cooperating jaw (6b) of the clamping means (6b, 7b) substantially

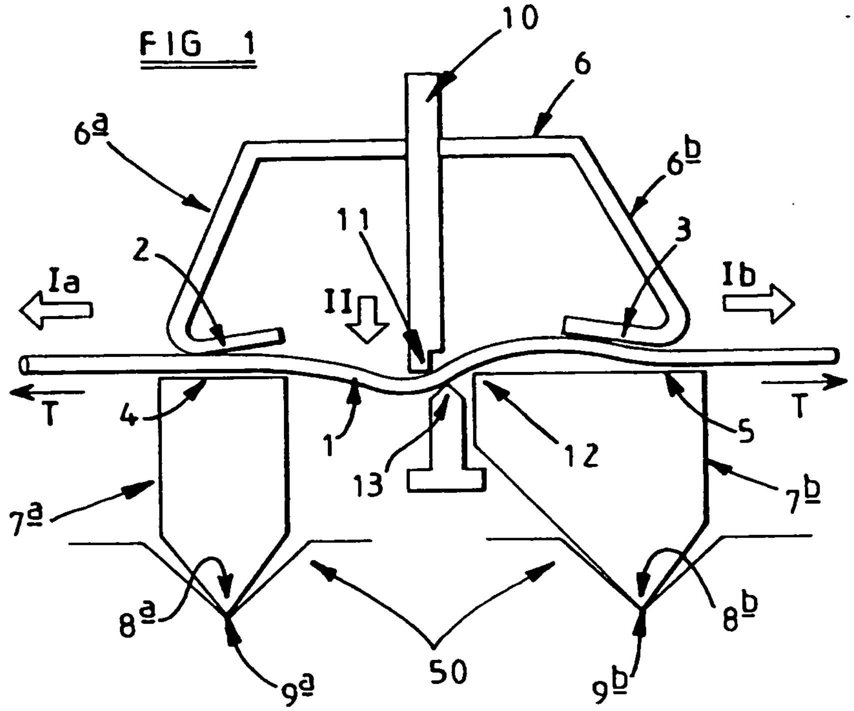
co-extensive therewith in order to firmly clamp an optical fiber (1) at said corner edge formation (12).

10 A tool for angled cleaving of at least one optical fiber or the like according to any of the preceding claims wherein the first mentioned shear force member comprises a double armed anvil (31) having an extension piece such as a transverse member or rod (33, 38) to one arm so that the anvil (31) is, in effect, single armed for transverse or line contact (34, 41) with a fiber (1), i.e. for the purpose of angled cleaving thereof.

11 A tool for angled cleaving of at least one optical fiber or the like according to claim 10 wherein the extension piece or transverse member or rod (38) is removable or movably mounted on the anvil (31) so that on removal or movement away from its operative extension position in relation to an arm of the anvil (31), the latter is restored to a double armed anvil for alternative perpendicular cleaving of a fiber (1).

12 A tool for angled cleaving of at least one optical fiber or the like according to any of claims 2 to 11 wherein the separate further shear force part or piece (26, 42) providing corner edge formation (27, 44) is adjustable or removable in relation to the substantially fixed part or jaw (7b, 29b) for obtaining variation in the angle of angled cleaving of the fiber (1).

FIG 1



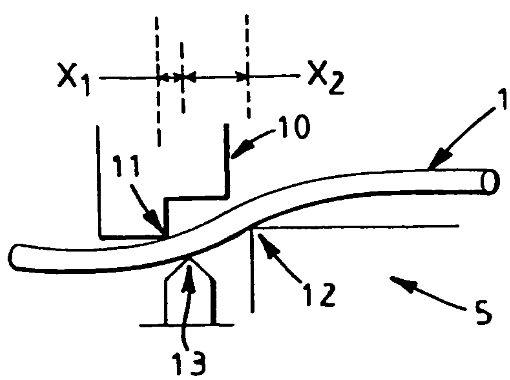
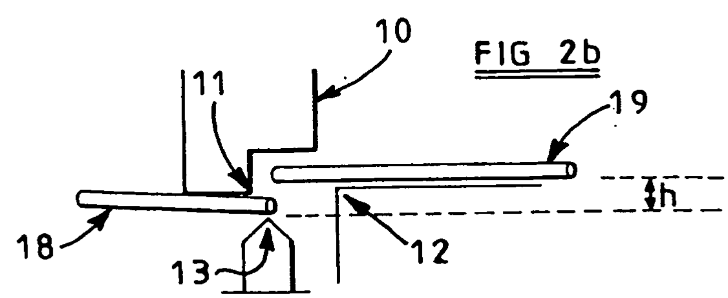


FIG 2a

FIG 2b



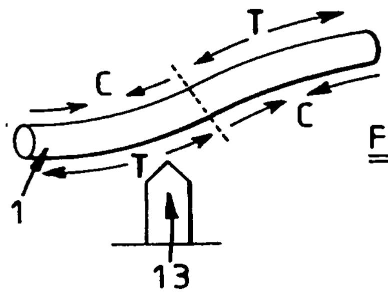


FIG 2c

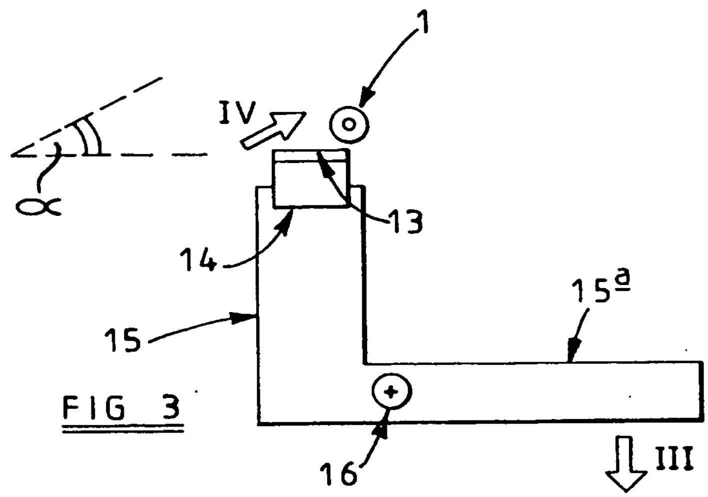


FIG 3

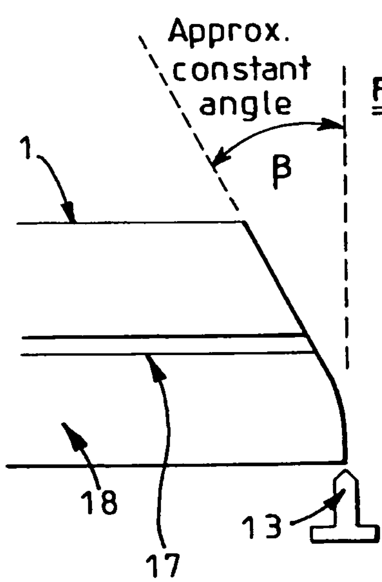


FIG 4a

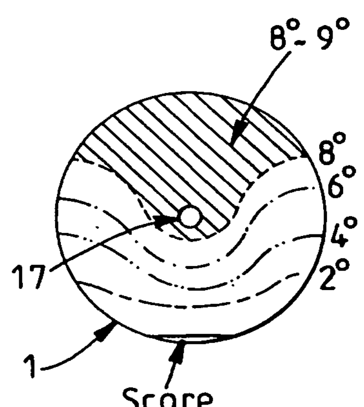


FIG 4b

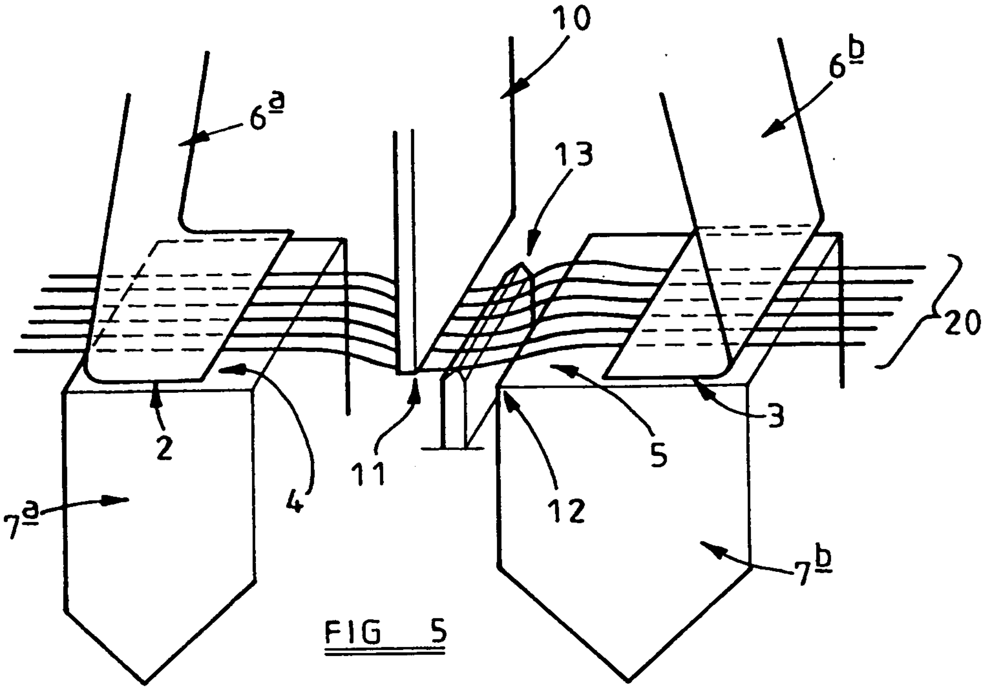


FIG 5

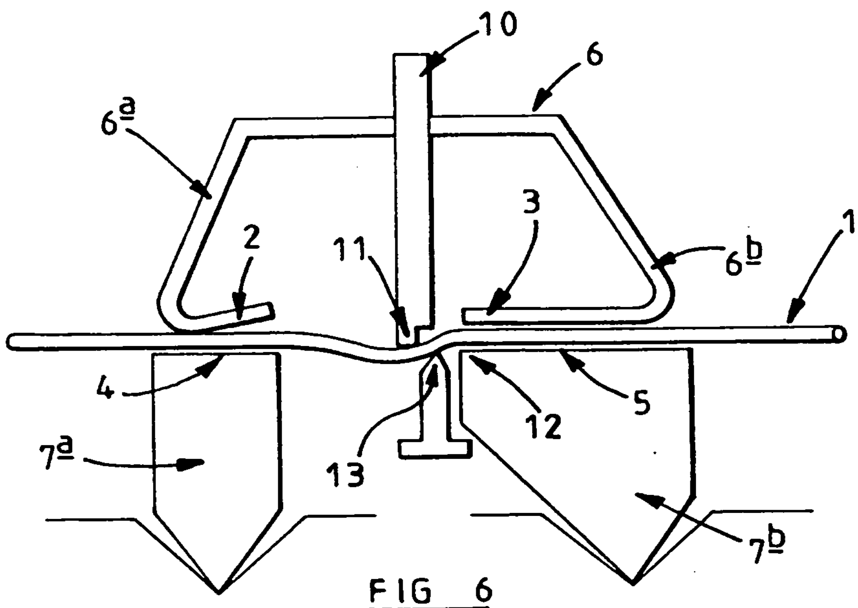


FIG 6

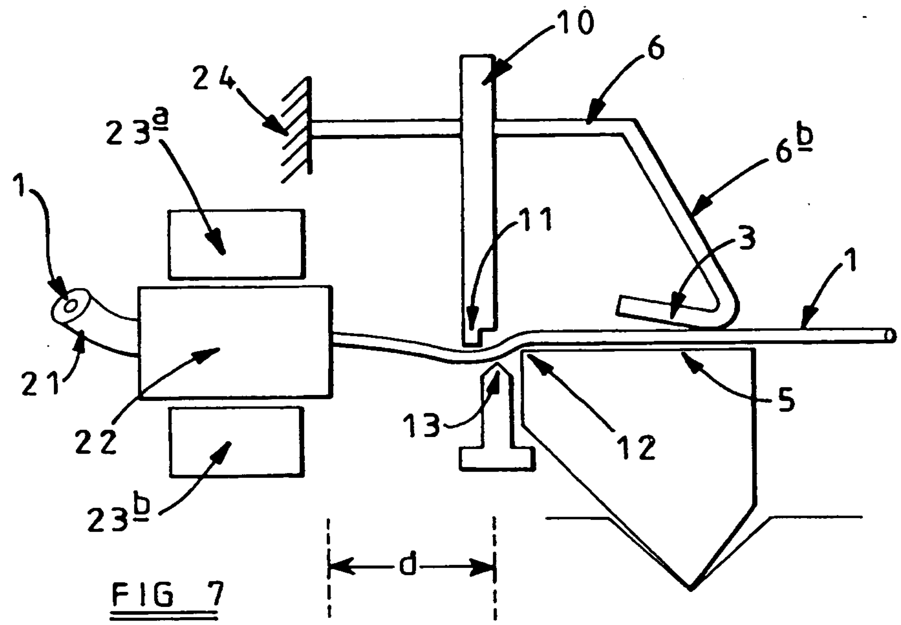
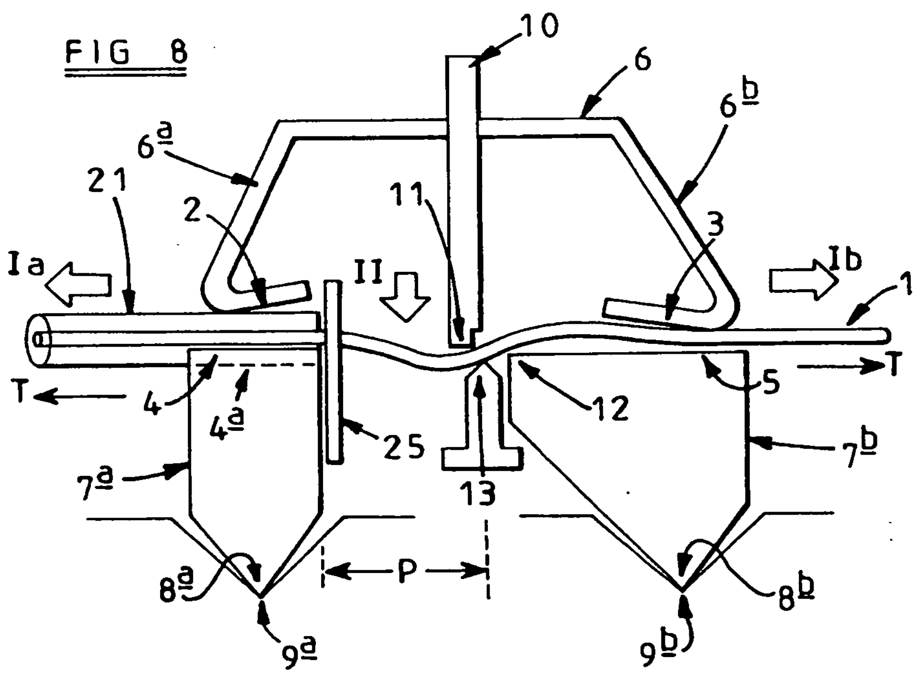

10
6
24
23a
6b
1
11
3
1
21
22
13
12
5
23b
d

FIG 7

FIG 8


10
6
6b
6a
21
11
2
3
Ia
II
Ib
1
T
4
4a
12
5
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P
8b
9a
9b

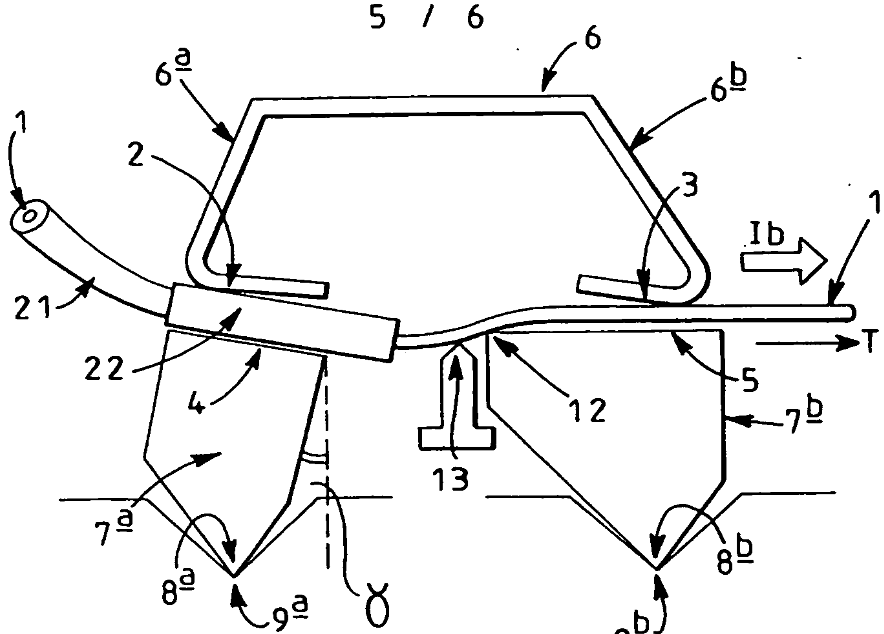

6
6a
6b
1
2
3
1
Ib
21
T
22
5
4
12
7b
13
7a
8b
8a
9a
γ
9b

FIG 9

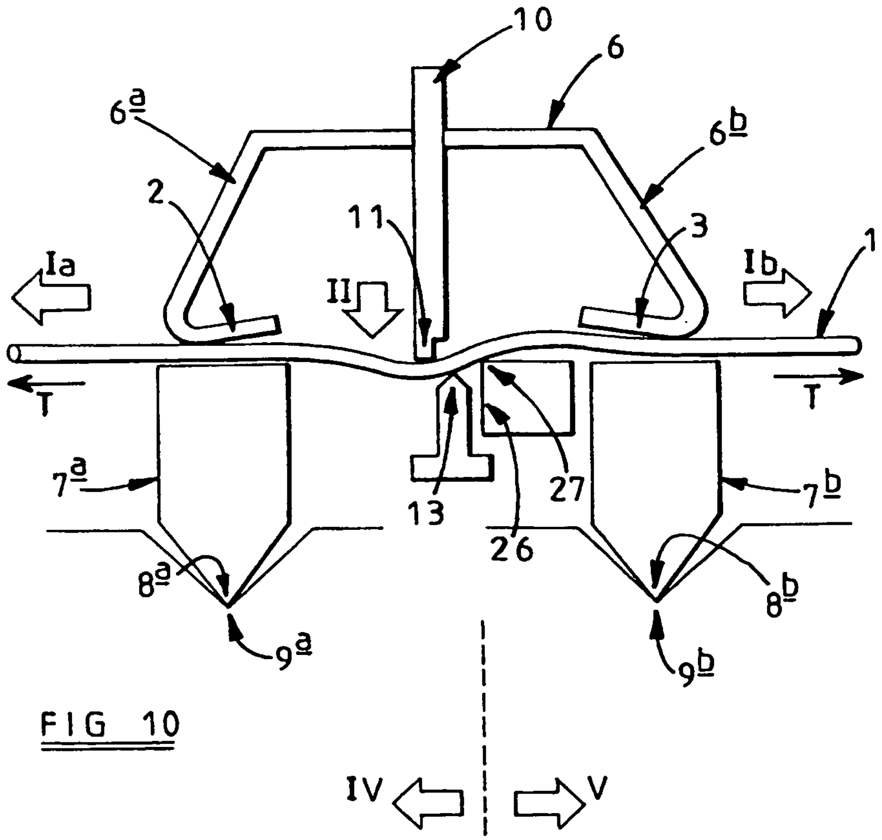

10
6
6a
6b
2
11
3
1
Ia
Ib
II
T
T
7a
7b
27
13
26
8a
8b
9a
9b
IV
V

FIG 10

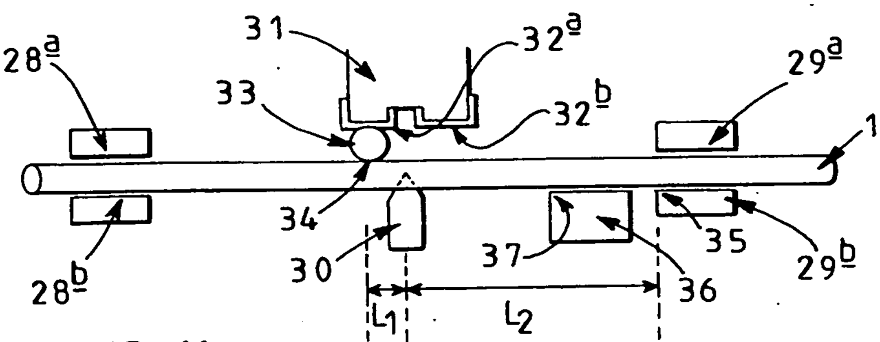


FIG 11a

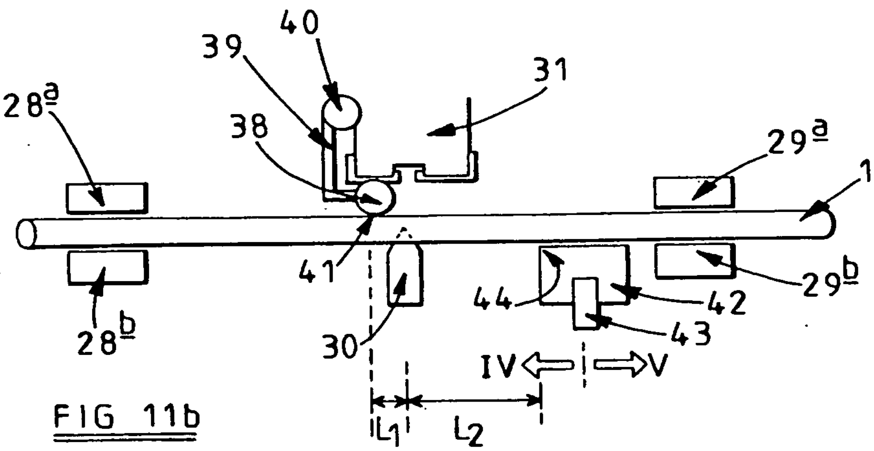


FIG 11b

FIG 11c

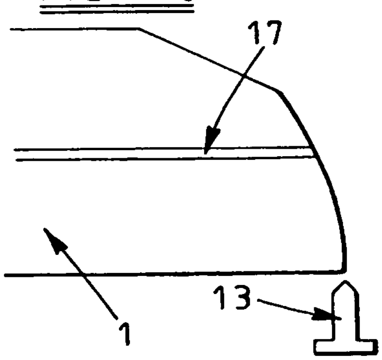
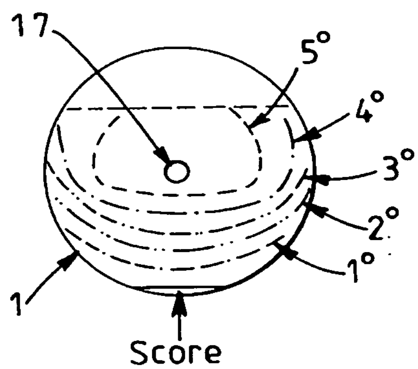


FIG 11d



INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 98/01598

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G02B6/25

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 312 468 A (YIN HUAN B ET AL) 17 May 1994 see column 3, line 28 - column 4, line 9; figure 2	1,5,6
Y		2-4,7-12
Y	WO 96 33430 A (OXFORD FIBER OPTIC TOOLS LTD ;MURGATROYD IAN JOHN (GB)) 24 October 1996 cited in the application see page 35, line 4 - page 38, line 29; figure 5	4,7-12
Y	US 5 123 581 A (CURTIS LYN ET AL) 23 June 1992 see the whole document	2,3

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 August 1998	21/08/1998

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Lord, R

1

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 98/01598

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2 287 552 A (MINNESOTA MINING & MFG) 20 September 1995 see page 11, line 20 - line 29; figure 5 -----	1

INTERNATIONAL SEARCH REPORT

Information on patent family members

Int. ional Application No
PCT/GB 98/01598

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